RECENT SEISMOLOGY.

I.—EARTH MOVEMENTS WHICH WE FEEL.

THE circumstances which led to the recent advances in seismological science are closely connected with an earthquake-like reformation in the policy of a foreign country. The country referred to is Japan, and the story of the changes it so suddenly effected is well known.

To bring about the new conditions engineers, architects, doctors, lawyers, surveyors, literati generally, together with representatives of a variety of trades, were invited to the birth of a new *régime*.

The engineers built their bridges, but found that they were shaken down; architects were disheartened that their houses were unroofed and subjected to processes of shattering; doctors learned that seismic disturbances might be followed by nervous prostration, tetanus and erysipelas; lawyers were perhaps perplexed when their opinion was required respecting the ownership of superimposed properties; the surveyors saw that the area of a piece of ground was not necessarily a constant quantity, and that gate-posts, on which bench-marks had been placed, might change their position by hopping—in short, one and all were impressed by the mobility of their near surroundings, and were often alarmed by rude awakenings.

The result of this was that an unusually keen interest was taken in all that pertained to earthquakes, and the new-comers, one and all—by speech, writing, or by special investigation—contributed to the advancement of seismological knowledge.

Amongst the many workers stationed in Tokio we find the names of Verbeek, Wagener, Knipping, Chaplin, Mendenhall, Ewing, Gray, Perry, Ayrton, West, Alexander and Knott; whilst amongst the Japanese, no less enthusiastic than their new colleagues, we see the names of Sekiya, Omori, Hattori, and many others. Outside assistance came from Bissett and Talbot in Yokohama, Fukushi in Sapporo, and a number of other workers throughout Japan.

At this time Tokio was in reality a city of many inventions, all of which were for the purpose of obtaining trustworthy information about earthquakes; their name was legion, and it is no exaggeration to say that of seismographs, seismoscopes and seismometers, more than one worked with at least fifty different devices.

One great problem which presented itself was to suspend a mass of material so that at the time of an earthquake it should practically remain at rest. The solution was first sought for in the bob of an ordinary pendulum. It being supposed that greater stability would be attained if the lengths of the pendulums were increased, three enthusiasts, in order to obtain a support from the roof timbers of their houses, cut holes through two ceilings, and the bobs of long pendulums were even to be seen in drawing-rooms.

Inasmuch as it was found that whenever a heavy earthquake occurred these pendulums were caused to swing in some instances so violently that apparatus in their vicinity was wrecked, attempts were made to render them dead-beat and next astatic, and a series of experiments were started which it would require pages to describe.

Following ordinary pendulums came horizontal pendulums, combinations of ordinary and inverted pendulums, rolling sphere and cylinder seismographs, ball and plate seismographs, parallel motion seismographs, and such a multitude of devices—not only for recording earthquakes, but also for timing them—that about 1883 it was decided to hold a public exhibition of earthquake apparatus. This was held in Uyeno Park; it lasted three days, and people flocked in such numbers to see the exhibits, that police assistance was called in, and the sight-seers were admitted in batches of about fifty.

Although in Japan, as a whole, there are on the average two or three earthquakes per day, whilst at many stations fifty to eighty shocks may be recorded during a year, because the disturbances came at unexpected times and from unexpected quarters, the appetite of the Tokio seismologists was so far from being satisfied that a series of experiments, which extended over several years, were inaugurated on artificially produced earthquakes.

The shakings were obtained at first by the fall, from heights up to about thirty feet, of a ball approaching a ton in weight, and subsequently by the explosion of charges of dynamite and gunpowder in boreholes.

The resulting vibrations—longitudinal, transverse, and vertical—were recorded at a series of stations so arranged in electrical connection that the time of any vibration could be noted to within a small fraction of a second.

Spare time was occupied in analysing earthquake registers and the carrying out of seismic surveys. The first of these was on an area of about nine acres, the next extended over the city of Tokio, whilst the last embraced a district some 500 miles in length, extending from the capital to the northern island.

In the first of these surveys a number of similar seismographs, one of which was in a pit, were connected together in the same manner that instruments had been connected when studying the effects of artificially produced disturbances; but with the latter, although a certain number of seismometers and seismographs were employed, the records were largely dependent upon information received on post-cards respecting the time at which a disturbance had occurred, and observations respecting its duration, direction, and severity.

This work, together with investigation on the volcanic phenomena of Japan, the more or less mysterious sea waves which occasionally inundated the coast, the supposed relationship that might exist between magnetic, electric, and seismic phenomena, the effect of earthquakes upon the lower animals, for studying which Prof. Sekiya kept a pen of pheasants, and a variety of other investigations formed interesting occupations for many.

On February 22, 1880, seismic enthusiasm was brought to a head by a very severe shaking, which gave to Yokohama the appearance of a town which had been bombarded. Taking advantage of the disturbed state of mind common not only to those who were repairing their roofs and chimneys, but to the whole community, a meeting was called, and in less than sixty minutes the Seismological Society of Japan, with its rules and regulations, was established. Many paid their subscriptions before they left the hall.

One great incentive to the work was competition between rival bodies, and many a time a member of the new Society, because his seismogram of the last quake was insignificant as compared with that obtained by a neighbour, after bitter controversy returned homewards from a meeting with a sad heart. At first these differences were regarded as the results of differences in the adjustment or construction of the instruments which had been employed, and it was not before sharp battles had been fought that it was recognised that the differences were due to differences in the localities of installation.

The feeling which at this time prevailed was not unlike that which characterises many sportsmen who, in the ordinary affairs of life, are everything that is admirable, but in the excitement of the field the desire to excel exceeds all others.

After seventeen years the seismic fever has abated, and we say with the poet—

> "*Haec olim meminisse juvabit.*"

Now what was the good of all this expenditure of ti and money in the endeavour to trap the fleeting earth quake? The earthquake-hunters of Japan, no doubt, saw a little that was before them; but now, when they stand beside the elaborate seismographs of the present day, costing 50*l.* or 100*l.*, and look backward upon the days when pins were propped up in rows to act as seismoscopes, and twopence would buy a bit of string and a bob for a pendulum, I do not think that it was ever anticipated that the study of earthquakes would lead to the knowledge which we now possess.

In seismometry we have seen the gradual evolution of several types of instruments which give faithful records of the amplitude, period, duration, and the time of occurrence of all ordinary earthquakes.

For this work we are greatly indebted to Ewing and Gray, and it is fair to say that the seismometry of Japan has done much to revolutionise seismometry throughout the world. The examination of earthquake records completely changed our ideas of earthquake motion, and we learned that nearly all the formulæ which up to this time had been employed to calculate earthquake elements had been founded upon a wrong hypothesis. The fact that the period of earthquake motion increased as it died out and as it radiated, coupled with a discussion of the observations made upon the movements which had occasionally been observed in the bubbles of levels, magnetographs, and other instruments, and, above all, that now and then unfelt earthquakes had been recorded, enabled one investigator to state, fifteen years ago, that it was "not unlikely that every large earthquake might with proper instrumental appliances be recorded at any point on the land surfaces of our globe"—a prediction which of late years has been amply verified.

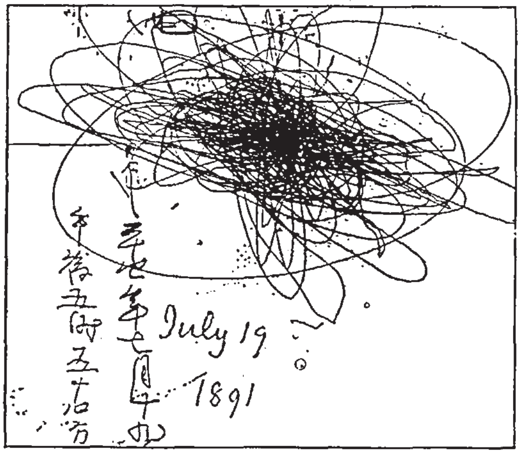


Fig. 1.—Static diagram of the earthquake of July 19, 1891, showing the complicated direction of motion common to most earthquakes. (Milne.)

It was found that modified forms of seismographs might be used to record the joltings of a railway carriage, and thus to indicate defective points along a railway line. Another application of seismometry has been to measure the steadiness of a locomotive, which in part depends upon the manner in which it is balanced. On Japanese railways this has been turned to practical account, with the result that a saving of from 1 to 5 lbs. of coal per mile per locomotive has often been effected. The modern seismograph is also used to measure the elastic vibrations of bridge work, buildings, and steamships.

The greatest material benefits which recent seismological investigation has conferred upon the world are those which have resulted in minimising the destruction of life and property. The builder now, rather than making a structure strong because an earthquake is strong, has before him definite measures and a clear knowledge of the character of the forces he may expect to meet. Given the dimensions and tensile strength of a body that has been overturned or shattered, we can calculate the maximum acceleration to which the same has been subjected, and that quantity is practically identical with that derived from a seismogram.

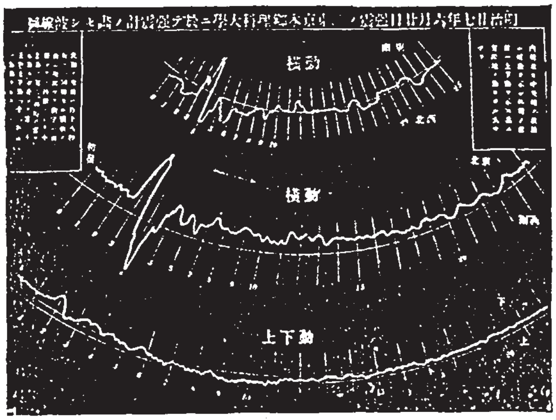
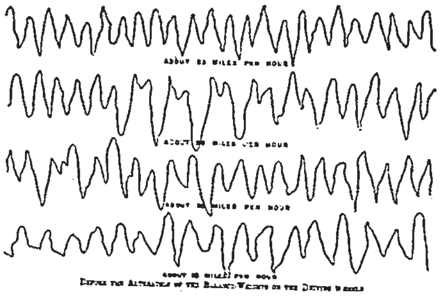
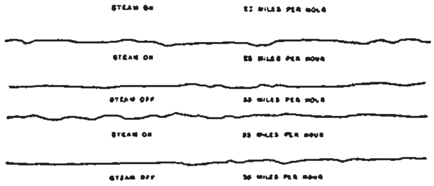


Fig. 2.—Earthquake of June 20, 1894, recorded at the Science College of the University of Japan. The upper figure is the S.E.-N.W. component; the middle, the N.E.-S.W. component showing preliminary vibrations, the shock, and concluding vibrations; and the lower, the vertical motion. The intervals are the seconds of time. (Ewing's Seismograph.)

By experience we know the maximum acceleration which may be expected in a given district or on a given site, and we can therefore proportion a structure to meet the known conditions.



Before the Alteration of the Balance-Weights on the Driving Wheels



After the Alteration of the Balance-Weights of the Driving-Wheels

Fig. 3.—The fore and aft motion of a locomotive as balanced in England and after rebalancing in Japan, by which a safe speed has been increased from 28 to 35 miles per hour, and coal saved. (Macdonald.)

The fact that the new rules take into consideration that buildings have to withstand measurable stresses, du to more or less horizontal displacements applied at the foundation, have been largely adopted in the building of houses and the works of engineers, is a testimony that they have been well worthy of consideration. The correctness of the new methods is found in the fact that in very many instances tall chimneys, as well as those of ordinary buildings, together with buildings themselves embodying the new principles, remain standing, whilst the old types have fallen or at least been shattered. When we remember that on June 15, 1896, Japan lost nearly 30,000 of her people by earthquakes and sea-waves, that on October 28, 1891, the loss of life was about 10,000, and the cost to restore railways and other works involved an outlay of approximately 3,000,000*l*., that the Calcutta earthquake on June 12, 1897, is to be followed by an expenditure of 35 lahks of rupees for the restoration of public works, for the payment of which the Chief Commissioner of Assam applies for a grant from the Imperial revenue, the importance of anything which will minimise the effects of these great catastrophes can not be over-estimated.

In Japan engineers and builders are already crystallising the results of experience and experiment, and stereotyped methods of construction are being gradually abandoned, with the result that after fire, flood, or earthquake, or as other opportunities present themselves, new types of structure are growing up, which have already shown themselves to be better than the old.

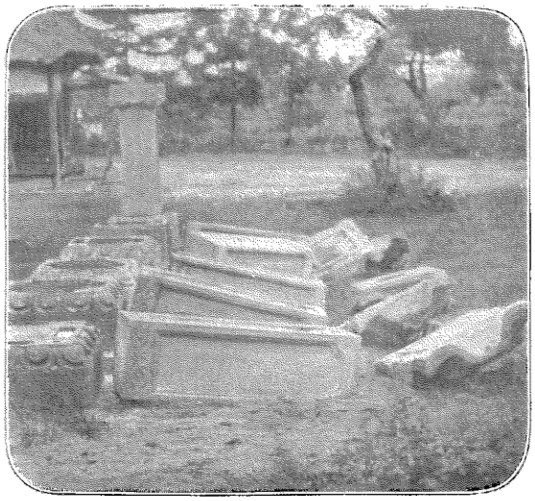


FIG. 4.—Gravestone as seismometers, indicating direction and intensity of movement. (Omori.)

Even if these results represented everything that the pioneers of the new seismology had achieved, they carry with them a feeling of satisfaction that the study of earthquakes has not been altogether unfruitful, but has led to that which is practical and simple in its application.

The experiments in which vibratory movements of the ground were produced by artificial means, whilst reproducing and affording an explanation of many phenomena observed or expected in earthquake disturbances, directed attention to others, the existence of which was for the first time rendered probable.

The velocity of propagation of wave motion evidently increased with the intensity of the initial disturbance; it was greater for vertical and normal than for transverse waves, whilst motion was propagated more rapidly to stations near an origin than between stations which were at some distance from the same.

The period of the movements increased as a disturbance died out, or as it radiated. A wave which had a slight notch upon its crest by the gradual growth of the riplet, as the motion radiated from its origin, was seen to change into a double wave. Within 50 or 100 feet of an origin, the first movement was due to a wave of compression, but beyond this distance a separation between normal and transverse movements was not observable.

The manner in which a shadow area, formed behind a cutting or hill, was invaded by movements creeping round the two ends of the obstruction was remarkable. These and many other results were confirmed and extended by actual seismograms obtained from a series of stations situated on a piece of ground less than ten acres in area. The motion on one side of this piece of ground was invariably so much greater than it was upon the other side, that it afforded an explanation of the peculiar distribution of ruin, sometimes observed in a city after a disastrous earthquake.

The fact that the side of greater motion was that, where the ground was soft, and the confirmation of this by observations in other localities, was a matter that attracted the serious attention of architects and builders. Another observation which has received many practical applications, especially in connection with the foundation of buildings, was that at a depth of 10 or 20 feet the movements of the ground were found to be less than they were upon the surface.

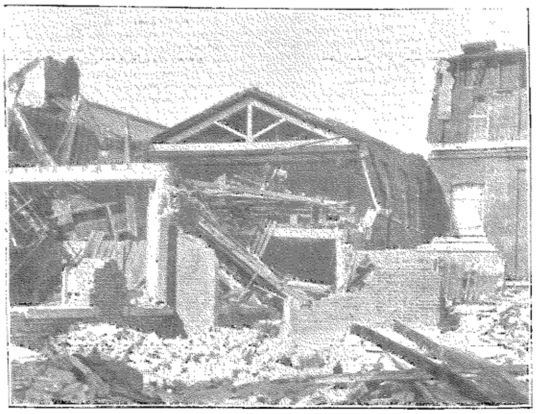


FIG. 5.—Destruction of an ordinary European structure (a cotton mill at Nagoya) by the earthquake of October 28, 1891. (Burton.)

The seismic survey of North Japan, which has been extended to cover the whole empire, shows clearly that the volcanoes, extending for the most part along the backbone of the country, have no immediate connection with the earthquakes, nearly all of which originate along the eastern seaboard. Many of the largest of these have their home beneath water which in certain places exceeds a depth of 4000 fathoms, and it is in these sub-oceanic recesses at the base of a continental dome where a certain class of geological activities, which from time to time are announced to us by the shaking of the ground, are most pronounced.

The earthquakes of one region have been separated from those of another, whilst the land area which was sensibly shaken by each disturbance is well known.

The advantage of these registers when, for example, we seek for a connection between earthquakes and lunar attraction, or the rising of the tide upon a coast, because these influences attain a maximum in different localities at different hours, must be apparent.

Thanks to Dr. C. G. Knott, who first subjected earth quake statistics to rigid analysis, to Dr. C. Davison, who so ably emphasised and extended these methods investigation, and to Dr. F. Omori, our knowledge of annual, semi-annual, diurnal, and other earthquake periodicities has been placed on a more certain basis than it formerly occupied.

Without entering into the observations which have been made upon magnetic phenomena, sea waves, sound phenomena, the behaviour of lower animals, and a variety of other subjects connected in a greater or lesser degree with exhibitions of seismic force, what has been said indicates that the study of earth movements, which we feel, have not been without profit.

In Japan, at its University, there is a chair of Seismology; a bureau, which in 1895 controlled 968 observing stations; whilst the Government give liberal support to a committee of engineers and architects, whose duty it is to carry out investigations which may lead to the mitigation of earthquake effects.

Notwithstanding the opportunities which Japan offers to make such investigations, it is worthy of note that two trained men were ordered by the Government of that country to report upon the recent earthquake in Assam. This they have done, and no doubt Japan is now in a position to avoid forms of construction of which she was hitherto without experience.

J. MILNE.

(*To be continued*).

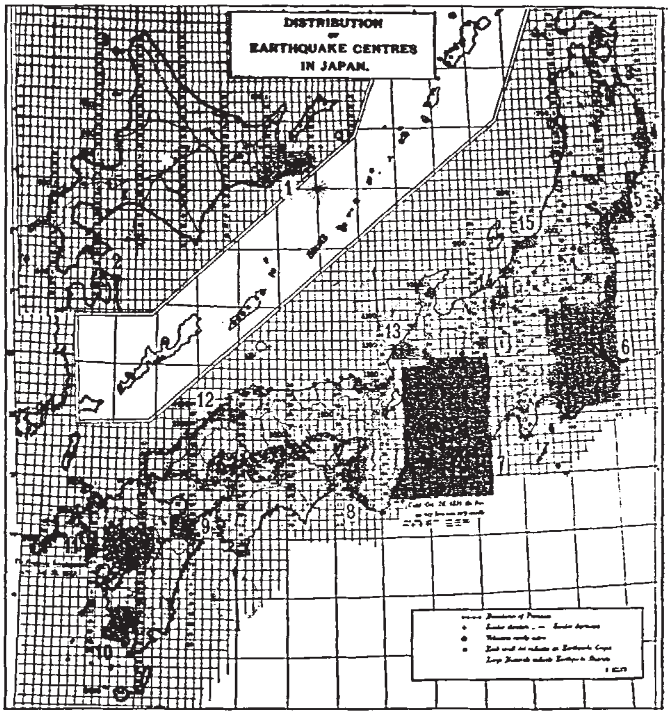


FIG. 6.—Map showing the origins of 8331 shocks recorded between 1885 and 1892 in Japan. The large dots indicate the positions of active volcanoes. The small dots indicate the origin of different earthquakes which group themselves into fifteen districts, each marked by a large numeral. (Milne.)

THE AREQUIPA OBSERVATORY.

PROF. PICKERING has conceived and carried to a successful issue many projects that require both mechanical skill and confidence in his resources. In the gradual development of these schemes, we have seen the modest row of volumes, that contained the annals of the Harvard Observatory prior to his directorate, increase to imposing proportions. We know how deftly he holds the strings that control the operations of many departments outside Harvard, and how efficiently he copes with the work that a whole army of astronomers submits to his examination. But assuredly the equipment and maintenance of the observatory at Arequipa will be remembered as one of his most successful achievements. We are apt to think of a subsidiary observatory, especially when situated in a position difficult of access, as one temporarily occupied for a definite purpose, and requiring but few instruments, mounted in buildings of slight construction. But the energy of Prof. Pickering has established in South America an observatory that a State government, having the resources of a public exchequer at its will, might look upon with satisfaction. We reproduce in Fig. 1 (p. 250) the general appearance of this astronomical station, some 8000 feet above the level of the sea, and a mere glance will show or suggest how varied must be the work of the observatory, in which all the telescopes under the different sheds are kept constantly employed through every clear night. In the illustration the observer's residence is on the extreme right. Starting from that point and taking the several buildings in order as we approach the left, we have first of all a laboratory with developing rooms attached, next a shed containing a 5-inch visual telescope, which leads on to another containing a 20-inch mirror of short focal length, figured by Dr. Common for the observation of the solar eclipse of 1889. We then pass a building containing the principal clocks and a transit instrument, and come to that containing the Bache telescope of eight inches aperture. Next to this is the 13-inch Boyden telescope under a cylindrical drum roof. To the left of this, and before we come to the buildings occupied by the assistants, is a telescope with a Voigtlander portrait lens as an objective in which are taken photographs of four hours' exposure of faint nebulous regions of considerable extent. To this list of instruments must now be added the Bruce photographic telescope, having an objective doublet of 24 inches aperture, and from Prof. Pickering's last report we learn that a transit photometer similar to that in use at Harvard has been erected. Photographs of all the bright stars from the North to the South Pole are now obtained when they cross the meridian on every clear evening, either at Cambridge or Arequipa or both.

We shall get a good idea of the use to which these instruments are put if we describe some of the illustrations that Prof. Pickering has given in the volume containing the "Miscellaneous Investigations of the Henry Draper Memorial." We have first of all a picture of the Southern Cross on which abuts a portion of Herschel's Coal-sack region, taken with the Bache telescope, exposure 127 minutes, covering an area ten degrees square. We might make this plate the excuse for discussing several points of great interest. First, should photographs represent the stars on paper as positives or negatives? Prof. Pickering, by his practice, is clearly in favour of exhibiting the stars as black dots on a white ground. In this decision he has been guided by the use of ordinary star charts, in which there has never been any question as to the most convenient method of representing stars, and to which astronomers have already accommodated themselves. With regard to the important question of the scale to be adopted, and which in this telescope gives three minutes to the millimetre, it will be admitted that it is too small for star charts, if faint stars are to be represented. Prof. Pickering says distinctly that the images are too near together to be conveniently studied. It is mainly for this reason that we do not reproduce the plate, which would have been interesting since it affords a good illustration of the difference between photographic and visual magnitudes. γ Crucis, which has a spectrum